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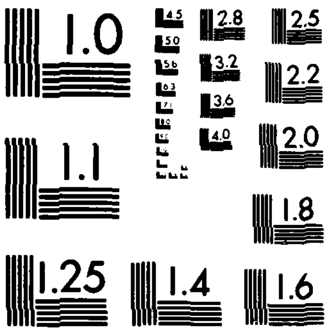
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CAORF 50-7917-02

CAORF TECHNICAL REPORT

SIMULATION EXPERIMENT

VALIDATION OF THE EFFECTIVENESS OF SIMULATOR EXPERIENCE VS REAL-WORLD OPERATIONAL EXPERIENCE IN THE PORT OF VALDEZ

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA

U.S. DEPARTMENT OF TRANSPORTATION

MARITIME ADMINISTRATION
OFFICE OF RESEARCH AND DEVELOPMENT

NATIONAL MARITIME RESEARCH CENTER
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15. Supplementary Notes

16. Abstracts

This study was designed to examine the effectiveness of simulator exposure and real-world observational experience in the Port of Valdez, Alaska in the learning of ship handling skills. Masters were tested on a simulated pilotage through the Valdez Narrows at the Maritime Administration's Computer Aided Operations Research Facility (CAORF) at Kings Point, New York. Performance data, measured as track deviation and percentage of time out of a prescribed tolerance band indicated equivalent performance for those masters with simulator experience or real-world observational exposure and significantly poorer performance for those masters with neither simulator nor real-world Valdez experience.

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Prepared By

Kent Williams, Ph.D.
Joel Goldberg, Ph.D.
Mark Gilder
CAORF Research Staff

November 1982

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

Prepared For

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ABSTRACT

A large number of ship masters gained their first exposure to the problems of transiting Valdez Narrows during research performed at the Maritime Administration's Computer Aided Operations Research Facility (CAORF) at Kings Point, New York. It is now appropriate to examine the effectiveness of this simulator experience. Whether simulator experience and real-world experience are comparable is an issue of particular relevance to those masters who have participated in a familiarization and certification program dealing with pilotage through the Valdez Narrows to the Port of Valdez. The present study was designed to examine the degree to which simulator experience received at CAORF was effective in improving pilotage performance compared to experience received in real-world situations. Four groups of masters were tested on a simulated pilotage through the Valdez Narrows. These groups consisted of:

- o Group 1 - Masters with simulated Valdez experience and real-world Valdez experience. (N=5)
- o Group 2 - Masters with no simulated Valdez experience but with real-world experience in the Valdez pilotage area. (N=5)
- o Group 3 - Masters with simulated Valdez experience but no real-world experience in the Valdez pilotage area. (N=5)
- o Group 4 - Masters with no simulated Valdez experience and no real-world experience in the Valdez pilotage area. (N=5)

Performance data, measured as track deviations and percentage of time out of a prescribed tolerance band, indicated equivalent performance for Groups 1, 2, and 3, and significantly poorer performance for that group which had neither simulator nor real-world experience in the Port of Valdez. The results indicated that experience with the CAORF Valdez operational exercises was as effective in improving performance as was real-world experience in the Valdez pilotage area.

CHAPTER 1

INTRODUCTION

That simulator experience can provide valuable assistance in the acquisition of marine-oriented skills has traditionally been accepted in the maritime industry. It is for this reason that the Port and Tanker Safety Act of 1978 requires the use of simulators in determining standards relating to the qualification and training of crews.

The study described in this report is one of a series of training and certification criterion programs being conducted at the Maritime Administration's Computer Aided Operations Research Facility (CAORF) at Kings Point, New York. The goal of this program is to develop performance criteria as a function of simulator experience and type of instructional process. Eventually, this and other studies will fulfill an executive directive, issued in March, 1977, which calls for the upgrading of deck officer certification through the use of simulators and training programs.

While attempts have been made to delineate which aspects of simulator experience contribute the most to performance, little attention has been paid to an empirical determination of the value of simulator experience used in conjunction with real-world exposure. This study attempts to determine the value of simulator experience to masters who either have or have not had specifically relevant real-world experience. In addition, the study also investigates the effectiveness of simulator exposure for the acquisition of specific shiphandling skills and the retention of such skills

It is essential that the comparability of simulator experience and real-world exposure be ascertained, if simulator experience is to be incorporated into training and certification criterion programs where specific functional objectives must be met. It is also necessary to determine the most effective combination of simulator experience and on-the-job training in the acquisition of shiphandling skills. In the present experiment the effects of previous on-the-job experience and simulator experience are separated in an attempt to compare the effect of simulator experience to that of real-world exposure on subsequent shiphandling performance.

The particular shiphandling performance objective chosen for this experiment is the demonstration of the knowledge and skills necessary for transiting the Valdez Narrows in Alaska. The approach to and departure from the Port of Valdez, Alaska, via the Valdez Narrows is indeed an important and timely concern and has served as the basis for a number of past studies conducted at CAORF. These studies have already yielded results immediately relevant to the safe transiting of ships in the Valdez Narrows. The current study continues this programmatic research.

1.1 HISTORICAL BACKGROUND

Before the first oil through the Trans-Alaskan Pipeline reached Valdez, there was great concern among environmentalists, state officials, and the Coast Guard for the ecology of the area and the safety of ships. The arrival of VLCCs and other ships of unprecedented size in these waters created concern regarding potential groundings and cargo spillage. Spillage from just

one large ship could ruin the Valdez Harbor, which is part of one of the world's great salmon fishing areas.

Valdez has several natural hazards that must be taken into consideration when attempting to assure safe passage through the Narrows to the Port of Valdez. Of greatest concern are winds up to 47 knots which have been recorded for sustained periods, with gusts of 75 knots or higher at times. "Williwaws," familiar to these Arctic regions, can also occur suddenly and, though lasting for short periods of time, can reach an intensity of 100 knots or more. Limited visibility occurs during both summer and winter months due to precipitation and fog. Middle Rock, midway across the Narrows, would be barely visible were it not for a lighted 30-foot (9.14 m) concrete structure installed by the Coast Guard. Beneath it, rock stretches out to a 400-yard base (366 m).

Certain precautionary measures have been suggested to minimize the possibility of accidents including limiting traffic to one way only, restricting passage when wind speed exceeds 40 knots, the use of tug escort under all conditions, and the recommendation that as part of the licensing requirement pilots may have simulator experience at an approved facility. With this in mind, eight Southwest Alaska pilots participated in an experiment carried out at CAORF (McIlroy, W., "A Review of Valdez Experiment," First CAORF Symposium, 1977) to determine conditions for safe passage through the Narrows. Other objectives of that experiment were to determine the effectiveness of newly developed precise navigational systems and the development of pilot responses to various power and steering failures.

The visual scene presented to these pilots, represented a realistic, colored panoramic view of the entire Valdez gaming area and included accurate placement of existing navigational aids and other prominent features used as cues by pilots negotiating the passage. In addition, both wind and current conditions were incorporated into this real-time simulation.

The performance data included measures such as:

- Track deviations from an idealized reference track.
- Time in and time out of tolerance ($\pm$ 2.5 beam widths).
- Rudder angle.
- Frequency of rudder reversals.

The results indicated a number of problem areas for pilots such as response to a combined power and steering loss without recovery.

Additional details of the results are beyond the scope of this report, but this early research served to establish the effectiveness of simulators as research and as training instruments.

As a result of the above experiment, the United States Coast Guard introduced a program which allowed 40 percent of a pilot's certification requirements to be obtained by way of simulation exercises. This led to the development of the Valdez Narrows operational exercises at CAORF, since this was the only U.S. facility to have a comprehensive Valdez Narrows and harbor data base. These exercises, developed during 1977, investigated the effectiveness of simulator exercises by providing structured experience for masters in the handling of a 165,000 DWT tanker in the Valdez Narrows under a variety of conditions.

The subjects for these exercises were masters from various shipping companies including Sun Oil Company, Cove Shipping, Keystone Shipping Company, Marine Transport Lines, the Trinidad Corporation, Gulf Oil Corporation, and Exxon.

For these operational exercises, the Valdez Narrows was simulated to a high degree of fidelity, presenting the level of information necessary for masters to successfully conduct the operational exercises along the USCG recommended track for ownship. Besides the visual representation, a full-size operational bridge provided appropriate shiphandling hydrodynamics including radar. In addition, various environmental factors were incorporated into the presentations.

The operational exercise program consisted of both classroom presentation of related topics such as shiphandling when failures occur and hands-on simulator practice of the concepts taught in the classroom. A team approach was used: while the bridge team worked the problem on the bridge, an observer team monitored its performance from a remote station equipped with extensive closed-circuit television and audio capabilities. The program for each subject was conducted over a five-day period.

Performance data were displayed during each run for the benefit of the proctor and observer teams seated at the monitoring station. During the program, vessel and navigational parameters indicative of shiphandling performance were automatically measured and recorded for analysis. The operational exercises proved to be effective as shown by improvements during the five-day period in trackkeeping, turning, wind compensation, radar utilization, and the handling of propulsion and steering failures.

For the present experiment, some of the subjects were chosen from masters who had partaken in the Valdez Narrows operational exercises. The subsequent performance of these masters conning a VLCC through the Valdez Narrows illustrates the degree to which previous exposure to pilotage on a simulator is effective in improving performance and how performance is affected by experience in real-world situations. The requirements of the experiment dictated the use of four groups of subjects listed below and shown in Table 1.

- Group 1 - Those masters who had participated in the Valdez operational exercises and who have also had real-world experience in the Valdez piloting area.

- Group 2 - Those who had no Valdez operational exercise experience but have had real-world experience in the Valdez piloting area.

- Group 3 - Those who had Valdez operational exercise experience but no real-world experience in the Valdez piloting area.

- Group 4 - Those who had no Valdez operational exercise experience and no real-world experience in the Valdez piloting area.

Comparison between Groups 1 and 2, in which real-world experience is held constant, permits us to assess the training effectiveness of a simulator.

Comparison between Groups 2 and 3, in which real-world Valdez experience is replaced by simulator experience, indicates whether the degree of skill obtained with a simulator is greater than, equal to, of less than the skill derived

TABLE 1. EXPERIMENT DESIGN

Group	Experience with Valdez Narrows			
	Real-World	No Real-World	Simulator	No Simulator
1 (N = 5)	○		○	
2 (N = 5)	○			○
3 (N = 5)		○	○	
4 (N = 5)		○		○

from observational experience transiting the Narrows in the real world.

Comparison between Groups 3 and 4, in which the absence of real-world Valdez experience is held constant, shows the value of simulator experience alone in improving track-keeping performance under simulated conditions.

Comparison between Groups 1 and 3, in which simulator experience is held constant, and comparisons between Groups 2 and 4, in which the absence of simulator experience is held constant, show the effects of observational experience gained by transiting the Valdez Narrows.

The results of all comparisons should have direct bearing on certification requirements, retraining, and especially the value of simulator training on real-world performance.

CHAPTER 2

METHOD

2.1 SOURCE AND BACKGROUND OF SUBJECTS

From May, 1977 through March, 1979, twenty groups of masters have participated in the Valdez Narrows operational exercises. The program of operational exercises familiarized masters with handling ships of 30,000 DWT to 250,000 DWT through the Valdez Narrows. The primary objectives of the program were to develop a high level of expertise in:

- o Familiarization with the Narrows and associated navigational aids.
- o Navigation of the Narrows, following a USCG-recommended track, using fixed navigational aids and other visual and radar cues.
- o Shiphandling under various environmental conditions.
- o Shiphandling under various failure conditions.

A total of 90 individual masters have been through these operational exercises, and many of them have had varying degrees of experience with the Valdez harbor itself. In view of this, it was found that there were numerous masters who fit the requirements for participation in the present validation experiment.

2.1.1 Test Subject Selection

Test subjects were selected from the aforementioned pool to conform with the following levels of experience.

I. Masters with previous experience at CAORF in the Valdez operational exercises who have also had extensive experience transiting Prince William Sound and the Valdez Narrows i.e., real-world experience. (5 required)

II. Masters with previous experience at CAORF in the Valdez operational exercises who had not had any real-world experience in Valdez Narrows. (5 required)

III. Masters with no CAORF experience in the Valdez operational exercises but who have had extensive experience transiting Prince William Sound and the Valdez Narrows. (5 required)

IV. Masters with backgrounds similar to the rest of the groups (e.g. mean years at sea, types of licenses held) but with no CAORF Valdez operational exercise experience and no real-world experience in the Valdez Narrows. (5 required)

2.1.2 Familiarization

All test subjects were provided with preliminary familiarization before participating in the experiment. Test subjects were shown the simulator wheelhouse, equipment, charts, visual scene, and shiphandling characteristics. They were also given the opportunity to observe a transit on the bridge of the simulated 165,000 DWT tanker that would be used in the experiment. This allowed each subject to be familiarized with the Valdez gaming area and the designated track which they would be

required to follow. The track was illustrated on the appropriate chart.

2.2 ENVIRONMENTAL SIMULATION

2.2.1 Environmental Data Base and Gaming Area

The experiment utilized the Computer Aided Operations Research Facility (CAORF) to perform the tests. A description of CAORF is given in Appendix A. The data base, which already exists at CAORF, consisted of the area surrounding the Valdez Narrows, including Bligh Island and Glacier Island in Prince William Sound and extending from the Valdez Arm through Valdez Narrows to points including the land masses visible from the Port of Valdez. (See Figure 1.) The visual scene included all navigational aids and the major topographical features necessary for pilotage through Valdez Narrows to the Port of Valdez.

2.2.2 Ownship Simulation

The handling and hydrodynamic characteristics of a 165,000 DWT tanker vessel were reproduced on the CAORF simulator. The characteristics of the tanker were as follows: the length of the tanker was 951 feet (290m), and the beam, 155 feet (947m). The mean draft for the ship in ballast was 28 feet (8.5m). These plus the other unique parameters such as hydrodynamic and aerodynamic coefficients were utilized by the computer program to produce realistic and accurate motion of this particular class of ship (ownship).

2.2.3 Bridge Equipment

The CAORF bridge, with equipment similar to that normally available on a tanker of 165,000 DWT includes:

- o Radars
- o Collision avoidance system
- o Engine throttle - bridge/engine room control
- o Gyro repeater
- o Communication equipment
- o Rudder angle indicators
- o Speed log
- o Ship's whistle
- o Steering stand
- o Relative wind and speed indicators
- o Rate of turn indicator
- o Two gyro repeaters on bridge wings
- o Fathometer

This equipment was used to provide ship control and navigation capability. Each responds with the same time delays encountered in the real world.

2.3 SCENARIO DESIGN

The following conditions were identical for all four groups:

Track - The designated track is shown in Figure 2. The starting point A to B is 028°T and changes to 045°T at point B and again to 080°T beyond point C.

Wind Conditions - Wind intensity varied from 40 knots, randomly gusting to 50, at extreme point A to 30 knots at Middle Rock and beyond. Wind direction was 005°T up to Middle Rock shifting to 020°T north of that point.

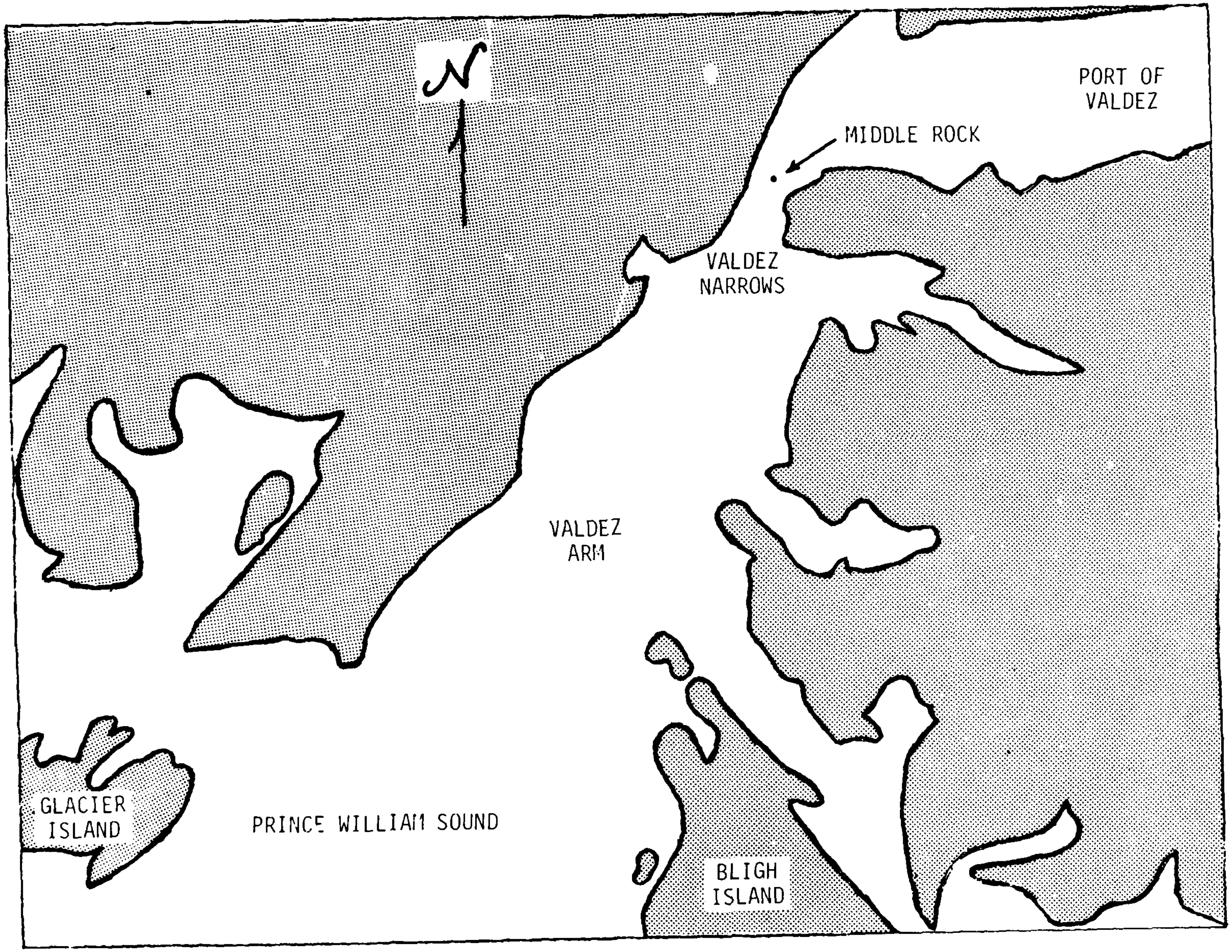

Figure 1. Port of Valdez Gaming Area

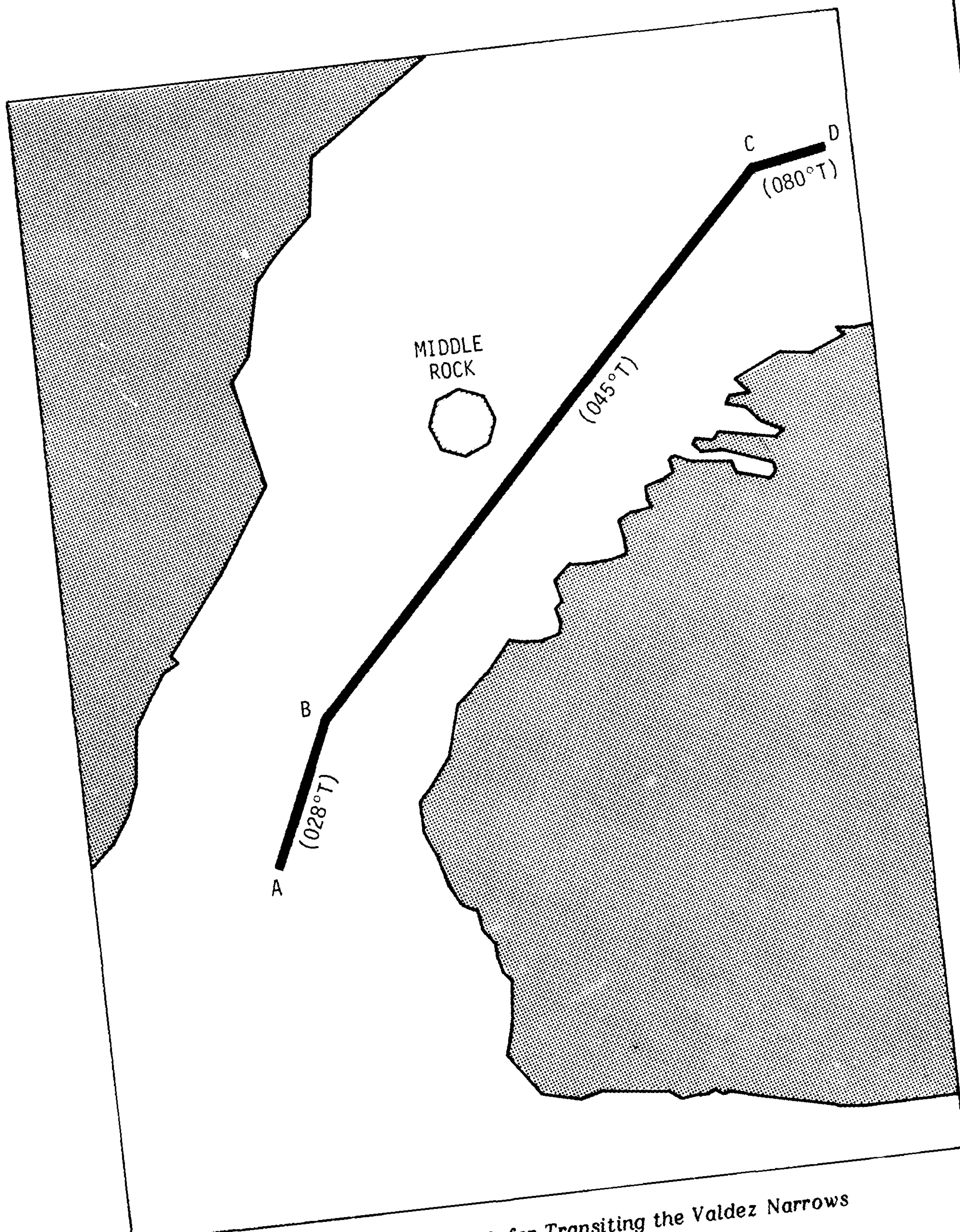

Figure 2. USCG Track for Transiting the Valdez Narrows

Current Conditions - The current speed was held constant throughout the experimental runs at 0.5 knots. The direction of the current was that of the normal outbound Valdez tide and had little effect on the ship.

Visibility and Traffic - All runs in the experiment were made under daylight conditions with unlimited visibility. No other traffic vessels were present in the harbor during any runs.

2.4 PROCEDURE

Regardless of group, each subject was briefed about the nature of the experiment. As previously described, they were familiarized with both the bridge instrumentation and the gaming area. To accomplish this, an experienced CAORF proctor took the ship through the Valdez Narrows along the USCG track line as shown in Figure 2. Each group of four successive runs was made with one subject from each of four test-subject groups. A subject was randomly chosen and allowed to transit the track as indicated (about 30 minutes). After this was completed, the subject left the bridge and the second subject was called in. This continued until all four subjects had been run once. The first subject was then called for his second run and so forth. All subjects were allowed a total of five trials.

2.5 PERFORMANCE MEASURES

2.5.1 Average Deviation from Reference Track

The instantaneous deviation of the ship's c.g. from the track line was recorded each 24 seconds during a run. Later, the average deviation for the run was computed from these data.

2.5.2 Time Out of Tolerance

A tolerance of ± 2.5 beam widths (± 390 feet) was superimposed over the reference track line. As the ship's actual track line is plotted, measures are recorded as to both the frequency (in terms of percent) of the time the ship's position was within tolerance and the frequency of the time the ship's position was out of the tolerance. These measures indicated how well the masters maintained vessel position with respect to the reference track which they were required to follow.

2.5.3 Rate of Acquisition

In addition to these measures, each subject's performance for each trial was examined. As the masters proceeded through the five runs, their performance relative to time out of tolerance and deviation from track with respect to the reference line should be expected to change, illustrating the benefits of practice across trials. This effect is reflected in the Analysis of Variance as the magnitude of the F ratio for the repeated measure (see Section 2.6, Analysis of Data). Subsequent contrasts among the means provided an indication of the differences in the rate of learning between each of the groups.

2.6 Analysis of Data

The data analyses for both performance measures were based on a two-between and one-within factors mixed design analysis of variance (ANOVA) for repeated measures. Table 2 shows the data matrix for such a design as applied to the present investigation. A detailed ANOVA is given in Table 3 and shc. s a summary of the comparisons wh ch were used to test for main effects and

TABLE 2. DATA MATRIX FOR TWO-BETWEEN SUBJECTS ONE-WITHIN SUBJECTS ANALYSIS OF VARIANCE

Valdez Experience			Trial				
Simulator	Real-World	Test Subject	1 (C_1)	2 (C_2)	3 (C_3)	4 (C_4)	5 (C_5)
Yes	Yes	S_1					
		S_2					
		S_3					
		S_4					
		S_5					
	No	S_6					
		S_7					
		S_8					
		S_9					
		S_{10}					
No	Yes	S_{11}					
		S_{12}					
		S_{13}					
		S_{14}					
		S_{15}					
	No	S_{16}					
		S_{17}					
		S_{18}					
		S_{19}					
		S_{20}					

interactions. Any significant F ratio is accompanied by the degree of confidence that the difference in the means tested did not occur by chance. That is, a $p < 0.05$ indicates a probability of better than 95% that the differences being tested are due to the conditions of the experiment.

TABLE 3. ANOVA - TWO-BETWEEN AND ONE-WITHIN SUBJECTS MIXED DESIGN

Source	df	MS	F
A	(a-1) = 1	$SS_a/1$	$MS_a/MS_{s(ab)}$
B	(b-1) = 1	$SS_b/1$	$MS_b/MS_{s(ab)}$
AB	(a-1) (b-1) = 1	$SS_{ab}/1$	$MS_{ab}/MS_{s(ab)}$
S (AB)	abn - ab = 16	$SS_{s(ab)}/16$	---
C	(c-1) = 4	$SS_c/4$	$MS_c/MS_{s(ab)c}$
AC	(a-1) (c-1) = 4	$SS_{ac}/4$	$MS_{ac}/MS_{s(ab)c}$
BC	(b-1) (c-1) = 4	$SS_{bc}/4$	$MS_{bc}/MS_{s(ab)c}$
ABC	(a-1) (b-1) (c-1) = 4	$SS_{abc}/4$	$MS_{abc}/MS_{s(ab)c}$
S(AB)C	ab (n-1) (c-1) = 64	$SS_{s(ab)c}/64$	---
TOTAL	anbc - 1 = 99		

A = Simulator experiene, 2 levels

B = Real-world (Valdez) exposure, 2 levels

C = Trials, 5 levels

CHAPTER 3

RESULTS

3.1 OFF TRACK DEVIATION

One of the three factors yielded significant main effects while the other two tended toward significance[1] as shown in Table 4. Means of Off Track Deviation for simulator experience, Valdez experience, trials and the four experimental groups over trials are presented in Appendix B.

Main Effects

(a) Simulator Experience - No significant difference of mean off-track deviation was found between the SIMULATOR group ($\bar{x}$ =-56.79) and the NO SIMULATOR group ($\bar{x}$ =-114.60) when considered independently of the other two factors. While not statistically significant, the large difference in the means indicates a trend toward better trackkeeping performance in the SIMULATOR group (Figure 3).

(b) Valdez Experience - The VALDEZ group produced a trackkeeping performance ($\bar{x}$ =-50.76) that approaches significance when compared with the NO VALDEZ group ($\bar{x}$ = -120.63); $F(1,16)=3.0663$, $p<.09$; Figure 4 shows

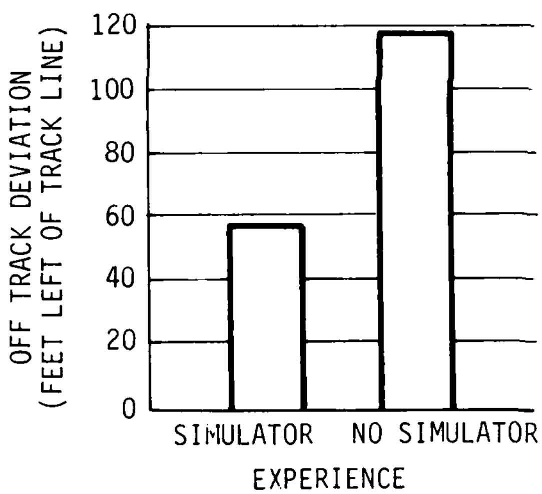

Figure 3. Mean Off Track Deviation for Subjects with Simulator and No Simulator Experience

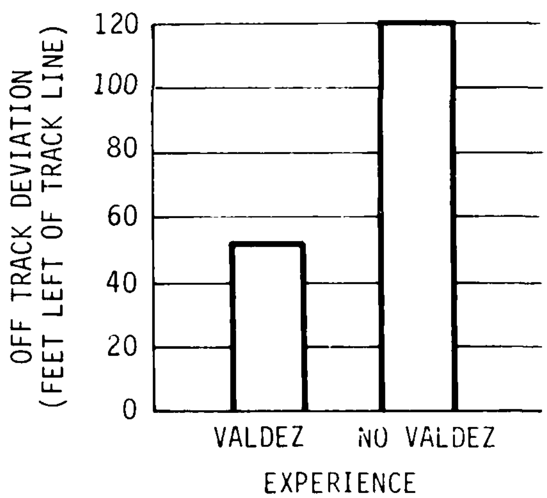

Figure 4. Mean Off Track Deviation for Subjects with Valdez and No Valdez Experience

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[1] The commonly accepted significance level for most research of this type is $p< .05$. The 0.05 level is somewhat arbitrary since any level of significance can be interpreted in terms of a probability statement. For example, a significance level of $p< 0.15$ indicates that one is 85% confident of the results (as compared to 95% above) or that there is a 15% probability that the results occurred by chance and are not due to the conditions of the experiment.

TABLE 4. ANOVA SOURCE TABLE FOR OFF TRACK DEVIATION

Source	F	Degrees of Freedom	Significance
Simulator vs. No Sim Experience	2.0988	1, 16	p< .16
Valdez vs No Valdez Experience	3.0663	1, 16	p< .09
Trials 1 - 5	9.5526	4, 64	p< .00004
Simulator x Valdez	2.1033	1, 16	p< .15
Simulator x Trials	0.2734	4, 64	NS
Valdez x Trials	2.4607	4, 64	p< .05
Simulator x Valdez x Trials	0.5468	4, 64	NS

these data considered independently of the other two factors.

(c) Trials - A significant main effect was found for the repeated measure F(4,64)=9.27, p<.001. As seen in Figure 5, subjects improved their trackkeeping dramatically in the first two trials and continued to improve more gradually over the remaining trials. Thus, across all groups, there was a learning effect present in the repeated trials.

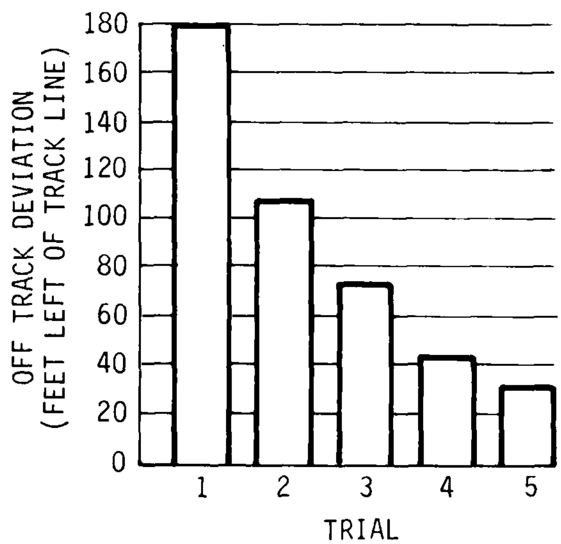

Figure 5. Mean Off Track Deviation for Trials 1 through 5

Interactions

(a) Simulator Experience and Valdez Experience - The interaction between simulator and Valdez was not statistically significant, yet a trend does exist in the data as seen in Figure 6. The major contributer to this effect is the NO SIMULATOR/NO VALDEZ group. To examine this, subsequent comparisons were performed.

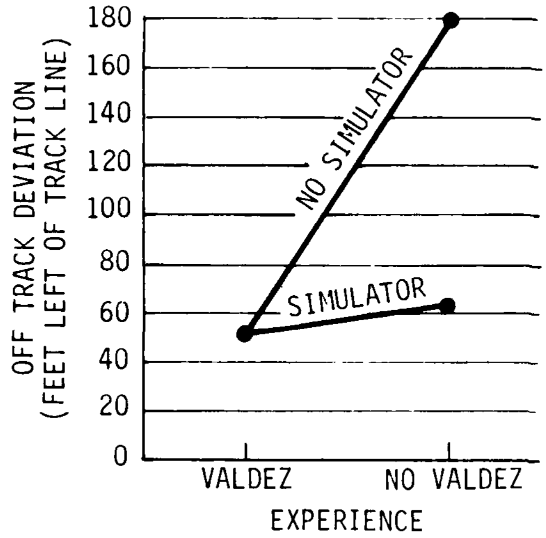

Figure 6. Mean Off Track Deviation for Simulator x Valdez Interaction

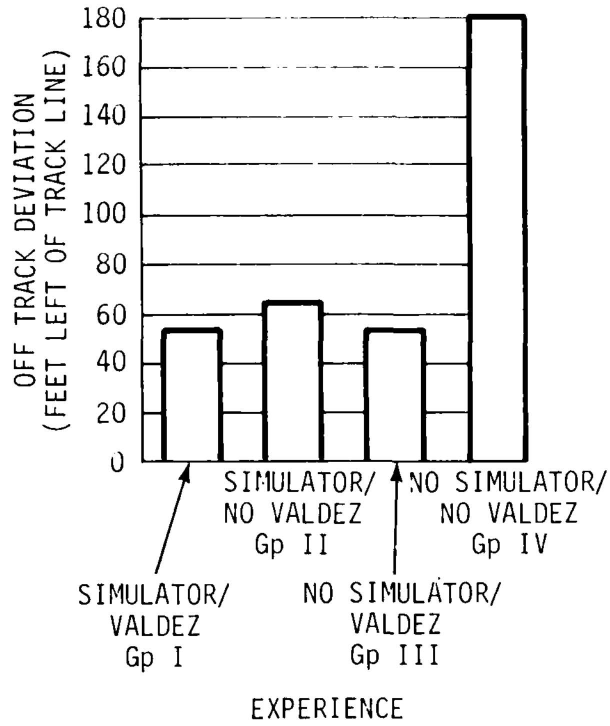

Figure 7. Mean Off Track Deviations for the Four Experimental Groups

Figure 7 presents the overall means of the four experimental groups for the off-track deviation measure. The SIMULATOR/VALDEZ ($\bar{x}$ =-50.79) group was not significantly different from either the SIMULATOR/NO VALDEZ ($\bar{x}$=-62.80) or the NO SIMULATOR/VALDEZ ($\bar{x}$=-50.70) group using the Duncan's Multiple Range Test (Appendix D, Section D.1). It was significantly different when compared to the NO SIMULATOR/NO VALDEZ ($\bar{x}$= -178.47) group, $p<.05$, which is apparent in Figure 7.

The SIMULATOR/NO VALDEZ group was not significantly different from the NO SIMULATOR/VALDEZ group, but was statistically different from the NO SIMULATOR/NO VALDEZ group, $p<.05$, using the Duncan's Multiple Range Test. The NO SIMULATOR/VALDEZ group was also significantly different from the NO SIMULATOR/NO VALDEZ group, $p<.05$. Thus, no meaningful difference was found to exist between the value of exposing masters to the Narrows on the simulator or in the real-world. However exposure by either means was beneficial.

(b) Simulator Experience and Trials - The simulator by trials interaction was not significant. Thus, the learning effect of repeated runs was not shown to be more prominent for the NO SIMULATOR group than for the SIMULATOR group.

(c) Valdez Experience and Trials -The interaction between Valdez experience and trials proved significant; $F(4,64) = 2.4607$, $p<.05$. As shown in Figure 8, those groups with Valdez exposure improve in performance substantially after the first trial and then reach asymptote on the following trials indicating that some limit of performance is being reached. Those groups with no

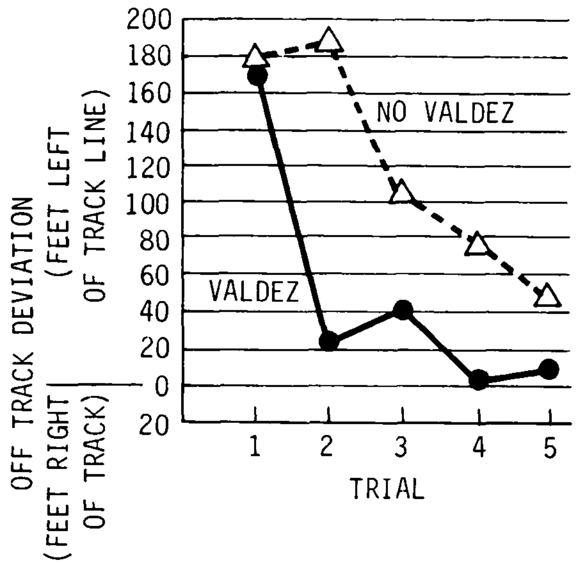

Figure 8. Mean Off Track Deviation for Valdez x Trials Interaction

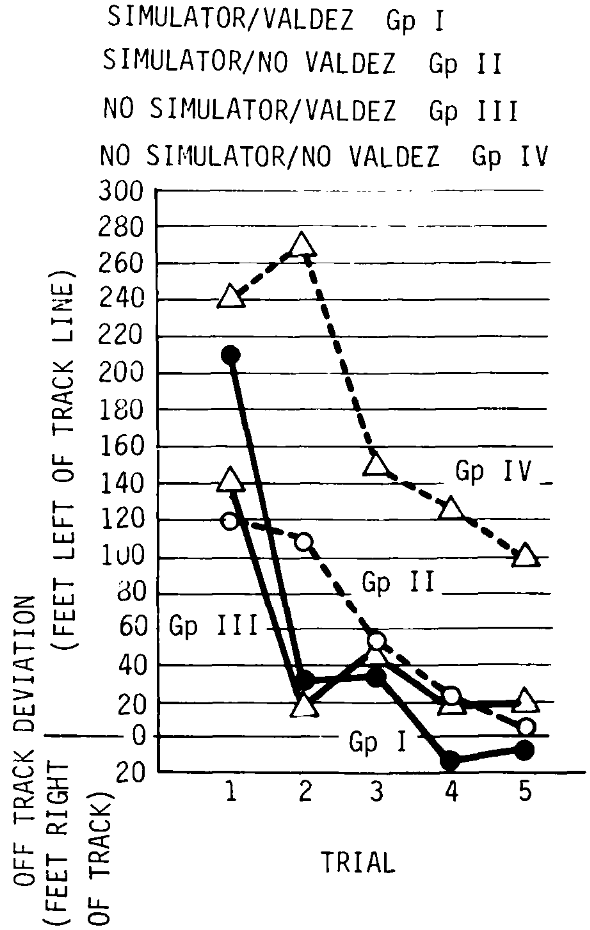

Figure 9. Mean Off Track Deviation for Simulator x Valdez x Trials Interaction

Valdez exposure initially showed a decrement of performance in trial 2 but then continued to improve in performance in trials 3, 4, and 5 though never reaching the same level of performance as those groups with Valdez exposure. It is evident that the NO VALDEZ groups are showing continued learning across trials. The VALDEZ groups do not show such an effect. It is these differences which resulted in a significant interaction.

(d) Simulator Experience and Valdez Experience by Trials - This interaction was not significant, but it is interesting to examine the performance of the four experimental groups (Figure 9). Both SIMULATOR groups tend to approach the asymptote rather rapidly after the third trial, whereas the NO SIMULATOR groups demonstrate that learning continues through trial 5. Comparisons show significant differences exist between the other three groups and the NO SIMULATOR/NO VALDEZ group at Trials 2 and 4 (Appendix D, Section D.1.1 to D.1.5).

3.2 TIME OUT OF TOLERANCE

The mean percent of time out of tolerance for simulator experience, Valdez experience, and trials for the four experimental groups were calculated (Appendix C). Table 5 contains the sources of variance along with the significant effects for these measures. Details of these results are discussed below:

<u>Main Effects</u>

(a) Simulator Experience - A non-significant main effect exists for simulator experience ($\bar{x}$ =11.95) compared to NO

TABLE 5. ANOVA SOURCE TABLE FOR OFF TRACK DEVIATION

Source	F	Degrees of Freedom	Significance
Simulator vs. No Sim Experience	2.1762	1, 16	$p < .11$
Valdez vs. No Valdez Experience	3.6414	1, 16	$p < .07$
Trials 1 - 5	8.5542	4, 64	$p < .0001$
Simulator x Valdez	3.5491	1, 16	$p < .07$
Simulator x Trials	0.0682	4, 64	NS
Valdez x Trials	3.6987	4, 64	$p < .009$
Simulator x Valdez x Trials	0.8026	4, 64	NS

SIMULATOR experience ($\bar{x}$ =19.76) and is illustrated in Figure 10.

(b) Valdez Experience - The main effect for Valdez experience approaches significance. Figure 11 shows that subjects with Valdez experience ($\bar{x}$ =10.80) found themselves out of tolerance less time than those subjects with no Valdez experience ($\bar{x}$ =20.90); $F(1,16) = 3.6414$, $p < .07$.

(c)Trials - The repeated measure, trials, is once again highly significant; $F(4,64) = 8.5542$, $p < .0001$. The groups all improved in their efforts to stay within tolerance as the experiment progressed (Figure 12).

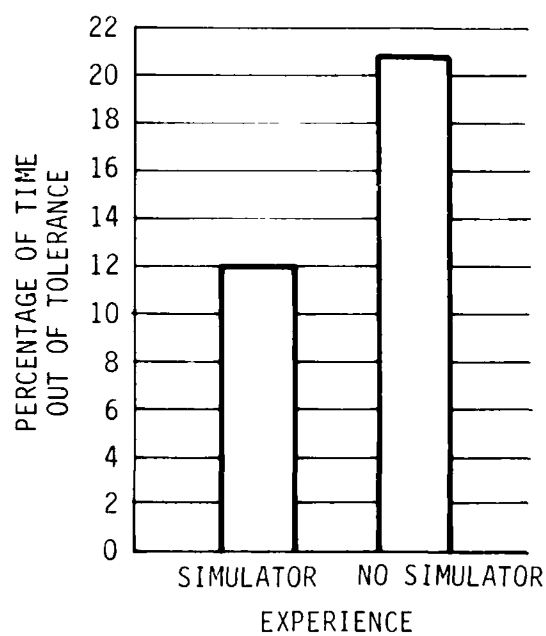

Figure 10. Mean Time Out of Tolerance for Subjects with Simulator and No Simulator Experience

Interactions

(a) Simulator Experience and Valdez Experience - The interaction between simulator and Valdez is found to approach significance and is presented in Figure 14. Comparisons using Duncan's

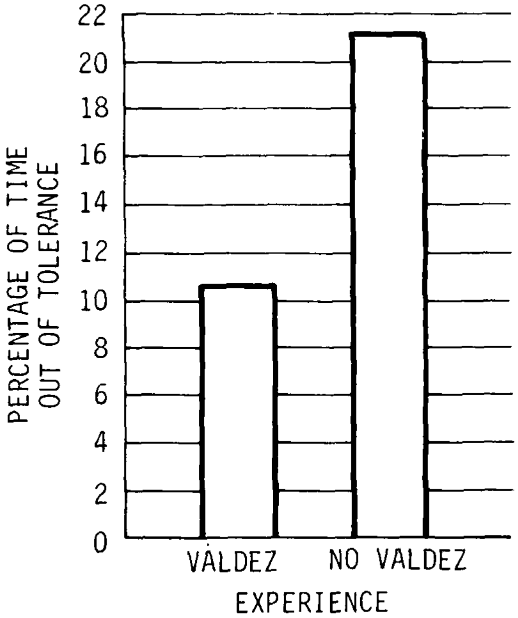

Figure 11. Mean Time Out of Tolerance for Subjects with Valdez and No Valdez Experience

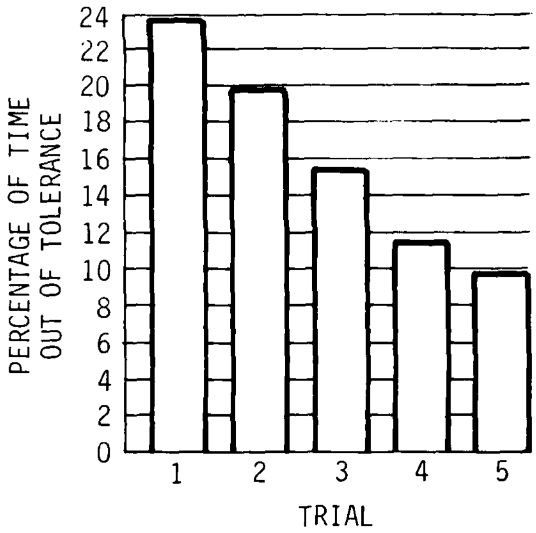

Figure 12. Mean Time Out of Tolerance for Trials 1 through 5

Multiple Range Test between the four experimental groups (Figure 13) show no differences between the SIMULATOR/VALDEZ ($\bar{x}$ =11.88) group and either the SIMULATOR/NO VALDEZ ($\bar{x}$ = 12.02) or the NO SIMULATOR/VALDEZ ($\bar{x}$ =9.72) group. (See Appendix D, Section D.2.0). However, the comparison with the NO SIMULATOR/NO VALDEZ ($\bar{x}$ =29.79) group was significant, $p < .01$. The SIMULATOR/NO VALDEZ group did not differ statistically from NO SIMULATOR/VALDEZ group. It did show a significant difference when compared to the NO SIMULATOR/NO VALDEZ group, $p < .01$. The NO SIMULATOR/VALDEZ group was also statistically different from the NO SIMULATOR/NO VALDEZ group, $p < .01$. Thus, in considering time out of tolerance, no appreciable difference could be ascertained between real-world and simulator exposure. Either exposure or both proved almost equally valuable.

(b) Simulator and Trials - The simulator by trials interaction was not significant.

(c) Valdez and Trials - A significant interaction was found between Valdez experience and trials; $F(4,64)=3.6987$, $p < .01$. As can be seen in Figure 15, the NO VALDEZ groups degrade in performance on trial 2 and then begin to show improvement while the VALDEZ groups improve quickly and continue until trial 5, where they degrade slightly. Trials 3 to 5 for this group appear to represent a ceiling effect for keeping the ship within tolerance.

(d) Simulator Experience and Valdez Experience by Trials - The three-way interaction was not significant. The data for the four experimental groups were compared in Appendix D (Sections D.2.1 to D.2.5) and are represented in Figure 16. The NO SIMULATOR/NO VALDEZ group was significantly different from the other three groups on all trials. It is interesting to note that on trial 2, the SIMULATOR/NO

VALDEZ group ($\bar{x}$ = 18.63) was significantly different from the NO SIMULATOR/VALDEZ group ($\bar{x}$ =6.12), $p < .05$. After this trial, the VALDEZ groups appear to reach asymptote quickly, while the NO VALDEZ groups continued to demonstrate learning.

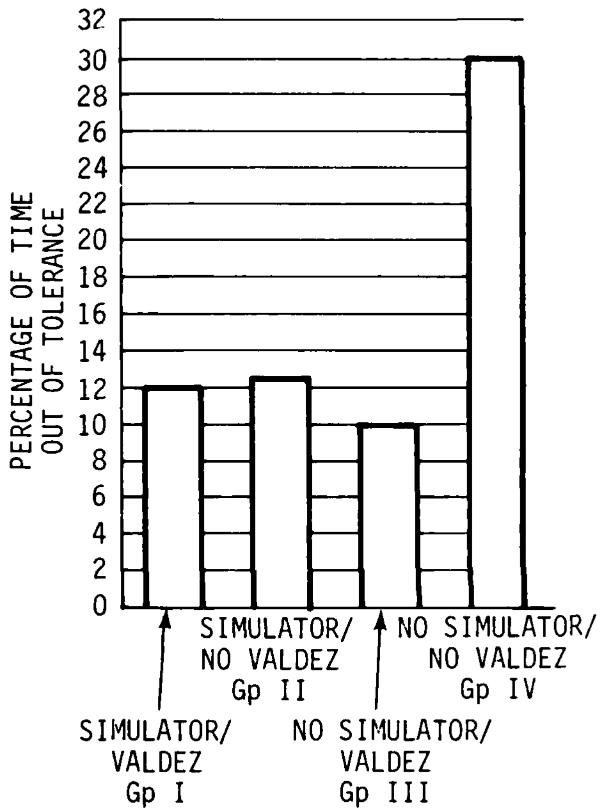

Figure 13. Mean Time Out of Tolerance for the Four Experimental Groups

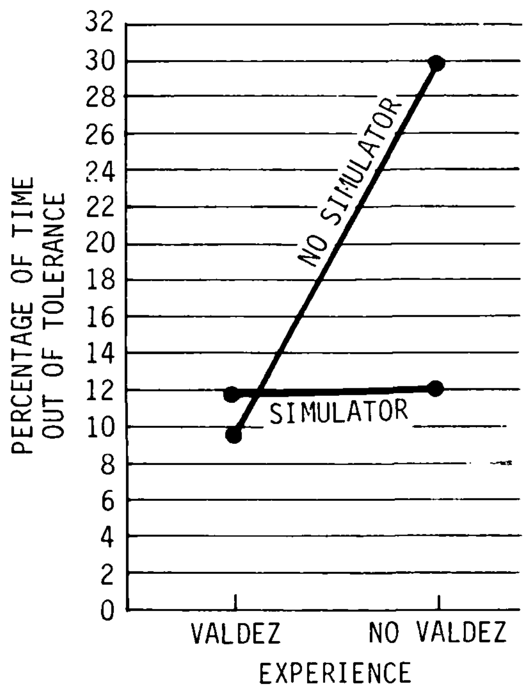

Figure 14. Mean Time Out of Tolerance for Simulator x Valdez Interaction

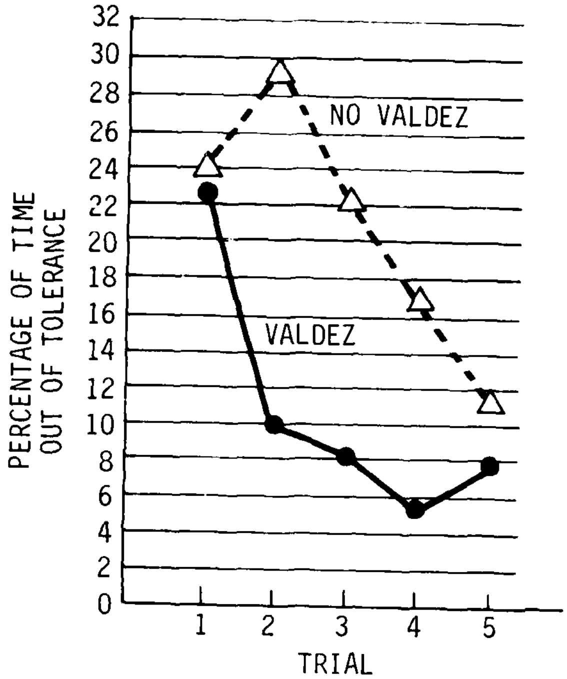

Figure 15. *Mean Time Out of Tolerance for Valdez x Trials Interactions*

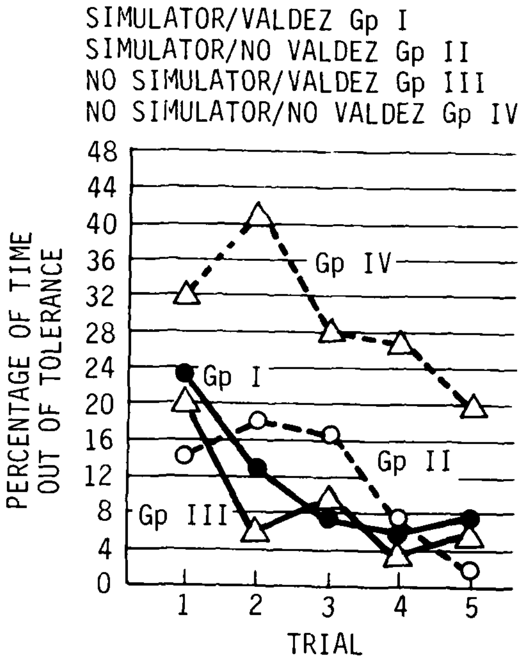

Figure 16. *Mean Time Out of Tolerance for Simulator x Valdez x Trials Interaction*

CHAPTER 4

DISCUSSION

The primary objective of the experiment was to compare the performance of masters who have had simulator experience maneuvering a simulated VLCC through the Valdez Narrows to the Port of Valdez to that of masters who have had real-world observational experience maneuvering VLCC's through the same area. In addition, masters who have had neither simulator nor real-world Valdez experience were compared to masters who have had either simulated or real-world Valdez experience or both. The results indicate quite clearly that performance did not differ among the groups having either simulator experience only, Valdez experience only, or both. However, each of these three groups exhibited significantly better performance than those subjects who had neither simulated nor real-world Valdez experience. Therefore, previous simulation experience and previous real-world exposure appear to influence to the same degree subsequent performance of masters maneuvering a simulated VLCC through the Valdez Narrows. In a like manner we can verify the intuitive assumption that previous experience transiting the Valdez Narrows should improve performance regardless of simulator exposure.

Another question is the impact of simulators as a valid representation of real-world experience. For example, is the training received on a simulator equivalent to that received by real-world exposure to the same learning objectives? A comparison between the performance scores of the NO SIMULATOR/VALDEZ and SIMULATOR/NO VALDEZ groups would reveal if any such differences exist. If the performance scores of both these groups were identical (i.e., statistically not significant), it may be concluded that the degree of shiphandling performance acquired on a simulator is equivalent to that which can be acquired from observational experience in transiting the Narrows in the real world. The comparison of these groups is shown in Figures 7 and 13. It is apparent that the performance measures for both the NO SIMULATOR/VALDEZ group and the SIMULATOR/NO VALDEZ group are identical. We may therefore conclude that masters with simulator experience perform as well as those who have actually made frequent transits through the Narrows.

The value of simulator exposure is also shown in the comparisons of performance data between those masters who have had experience (i.e., subjects who had participated in the operational exercises) in the simulated Valdez gaming area and those who have had no simulator experience in the gaming area. To evaluate the significance of simulator experience alone, the appropriate comparisons are between the SIMULATOR/NO VALDEZ and NO SIMULATOR/NO VALDEZ groups. These data are shown in Figures 7 and 13 and indicate a significant difference between the mean scores of both groups. These results show that simulator experience provides a major contribution to ship control measured by accuracy of trackkeeping in the Valdez gaming area.

The value of simulator experience is even more strongly shown when the SIMULATOR/VALDEZ group is compared to the SIMULATOR/NO VALDEZ

group. In this case, we are able to judge the combined effect of both simulator and real-world experience to simulator experience alone. Once again it is evident that performance measures for these groups are in close agreement with each other (Figures 7 and 13), and that little gain in trackkeeping ability is achieved by real-world experience among subjects who have already had exposure to simulator operational exercises.

Another finding which should be addressed is the learning effect across repeated trials on the Valdez scenario. As referenced in Tables 4 and 5, both performance measures showed highly significant practice effects across trials. The specific inter-trial relationships shown in Figures 5 and 12 indicate major improvements in performance occurring in the early trials and a gradually leveling off with additional trials. The most significant improvement occurs in trial 2. However, this improvement does not occur for the NO SIMULATOR/NO VALDEZ group. (See Figure 9.) This would indicate that any learning of skills on a simulator is relatively stable when tested at a later date. Performance peaked after the second trial, especially for the SIMULATOR /NO VALDEZ group which represented masters who had participated in the Valdez operational exercises but did not have any similar or real-world experience or intervening simulator exposure. The subjects in this group originally participated in the operational exercises anywhere from six months to two years prior to the present study. Figures 7 and 13, show that their performance is the same as masters who had intervening Valdez experience.

Apparently, the shiphandling capabilities acquired through simulation alone have been retained over a period of time without intervening practice of the specific skills either on a simulator or through real-world observation exposure. The shiphandling skills developed in the operational exercises has thus far been effective in making this six-month to two-year retention possible. It would be important, however, to be able to assess at what point a specific skill begins to require retraining in order to maintain a particular performance level.

It is generally assumed that refresher training contributes substantially to the long-term retention of learned skills. A practical application would be the case of a mariner who has been away from duty for a prolonged period of time or on another size vessel and is not up to his previous ability. Such an individual could profit from some refresher practice before returning to duty. A simulator with sufficient high fidelity could be used for assessing the level of a mariner's peformance in a particular gaming area, and could provide both the practice and the necessary geographical familiarization (e.g. complexity of the harbor) to bring a person up to previous levels of shiphandling performance.

Those subjects who participated in the simulated exercises at CAORF can be expected to show a decrement in performance at some time in the future if they have no opportunity to practice the skills. It would be ideal if CAORF participants who had no real-world exposure to the Valdez area could be brought into CAORF periodically for skill assessment and evaluation of the amount of practice necessary to restore an ability level. This would provide valuable information about when and how much refresher practice would be needed for a particular harbor. The likelihood of such an evaluation is not good since most of the masters who participated in the exercises hope that

they will be able to apply their skills in Valdez. It was difficult enough to obtain the captains' participation in the present experiment since so many mariners who have been through the operational exercises have subsequently been exposed to Valdez.

It is in order here to suggest future experimentation that addresses the problem of retention and retraining. Several groups of masters could be recruited to participate in a structured training program. Periodic simulator evaluation of the amount of retraining needed to re-establish the ability level attained during the original training could be planned for several different intervals (e.g. every six months versus every year). The different intervals could be examined for long-term retention effectiveness, which could provide information that would establish critical time periods for skill assessment and subsequent retraining.

In summary, the present investigation has demonstrated the validity of simulator experience as used in previous exercises and research. It has been shown to be an effective tool in improving performance regardless of a subject's previous exposure to real-world experiences. The results of this investigation serve to validate the Valdez Narrows operational exercises as formulated at CAORF and in general represents a cost-efficient method of improving shiphandling skills.

APPENDIX A

THE COMPUTER AIDED OPERATIONS RESEARCH FACILITY (CAORF)

A.1 DESCRIPTION OF CAORF

CAORF is the sophisticated ship-maneuvering simulator operated by the U.S. Maritime Administration for controlled research into man-ship-environment problems. Controlled experiments, which might require several vessels, cannot be performed readily in the real world and would certainly be ruled out for testing situations that involve potential danger. Such experiments can be performed safely and easily at CAORF. A simplified cutaway of the simulator building is shown in Figure A-1 and the relationships among the major subsystems are illustrated in Figure A-2.

All actions called for by the watch officer on the bridge are fed through a central computer that alters the visual scene and all bridge displays and repeaters in accordance with the calculated dynamic response of ownship and the environmental situation being simulated. CAORF has the capability of simulating any ship, port, or area in the world. The major subsystems are:

- **Wheelhouse,** which contains all equipment and controls needed by the test subject watch officer to maneuver ownship through a scenario, including propulsion and steering controls, navigational equipment and communication gear.
- **Central Data Processor,** which computes the motion of ownship in accordance with its known characteristics, models the behavior of all other traffic ships, and drives the appropriate bridge indicators.
- **Image Generator,** which constructs the computer-generated visual image of the surrounding environment and traffic ships that is projected onto a cylindrical screen for visual realism.
- **Radar Signal Generator,** which synthesizes video signals to stimulate the bridge radars and collision avoidance system for the display of traffic ships and surrounding environment.
- **Control Station,** from which the experiment is started and stopped, traffic ships and environment can be controlled, mechanical failures can be introduced, and external communications with ownship's bridge can be simulated.
- **Human Factors Monitoring Station,** from which unobtrusive observation and video recording of test subject behavior can be carried out by experimental psychologists.

A.2 SIMULATED BRIDGE

The simulated bridge consists of a wheelhouse 20 feet (6.1 m) wide and 14 feet (4.3 m) deep. The equipment on the CAORF bridge is similar to that normally available in the merchant fleet and responds with realistically duplicated time delays and accuracy. The arrangement is based on contemporary bridge design and includes the following equipment:

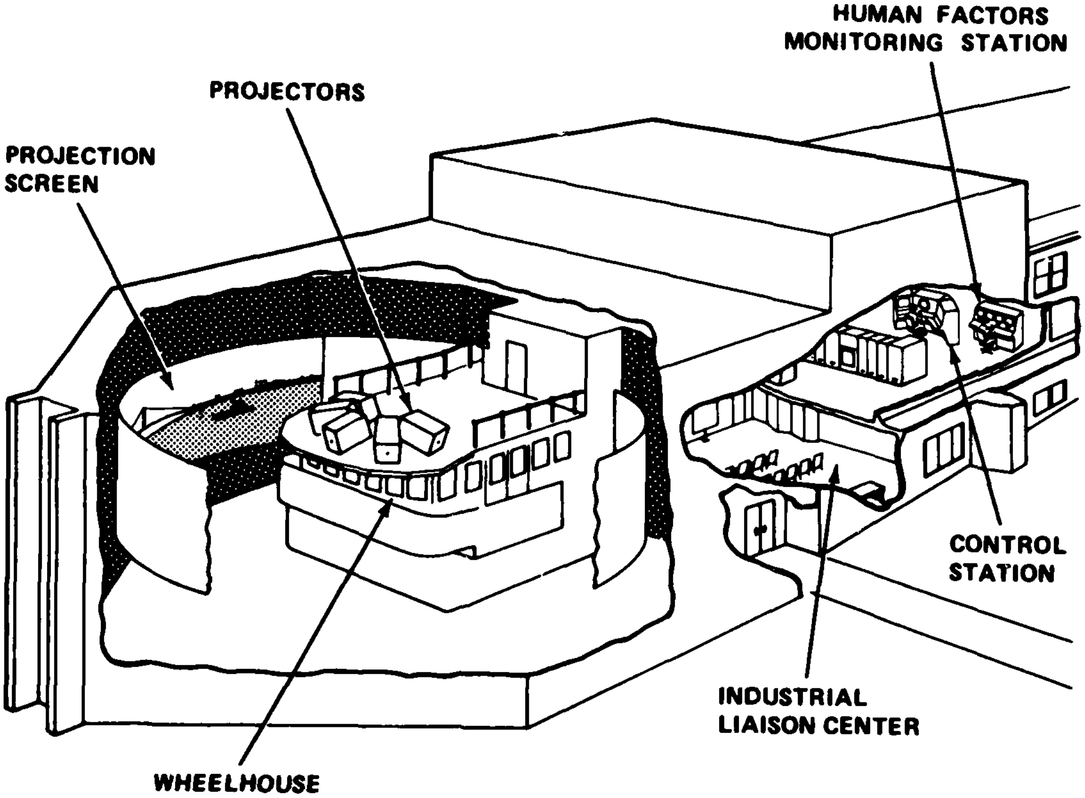

Figure A-1. Cutaway of CAORF Building

- **Steering Controls And Displays** - a gyropilot helm unit with standard steering modes, rate of turn indicator, rudder angle/rudder order indicators, and gyro repeaters.

- **Propulsion Controls and Displays** - an engine control panel (capable of simulating control from either bridge or engine room) containing a combined engine order telegraph/throttle, an rpm indicator and a switch for selecting the operating mode, such as finished with engine, warm up, maneuvering and sea speed.

- **Thruster Controls and Displays** - bow and stern thrusters and their respective indicators and status lights.

- **Navigation Systems** - two radars capable of both relative and true motion presentations, plus a collision avoidance system. Capability exists for future additions such as a digital fathometer, Radio Direction Finder, and Loran C and Omega systems.

- **Communications** - simulated VHF/SSB radio, docking loudspeaker (talkback) system, sound powered phones and ship's whistle.

- **Wind Indicators** - indicate to the bridge crew the true speed and direction of simulated wind.

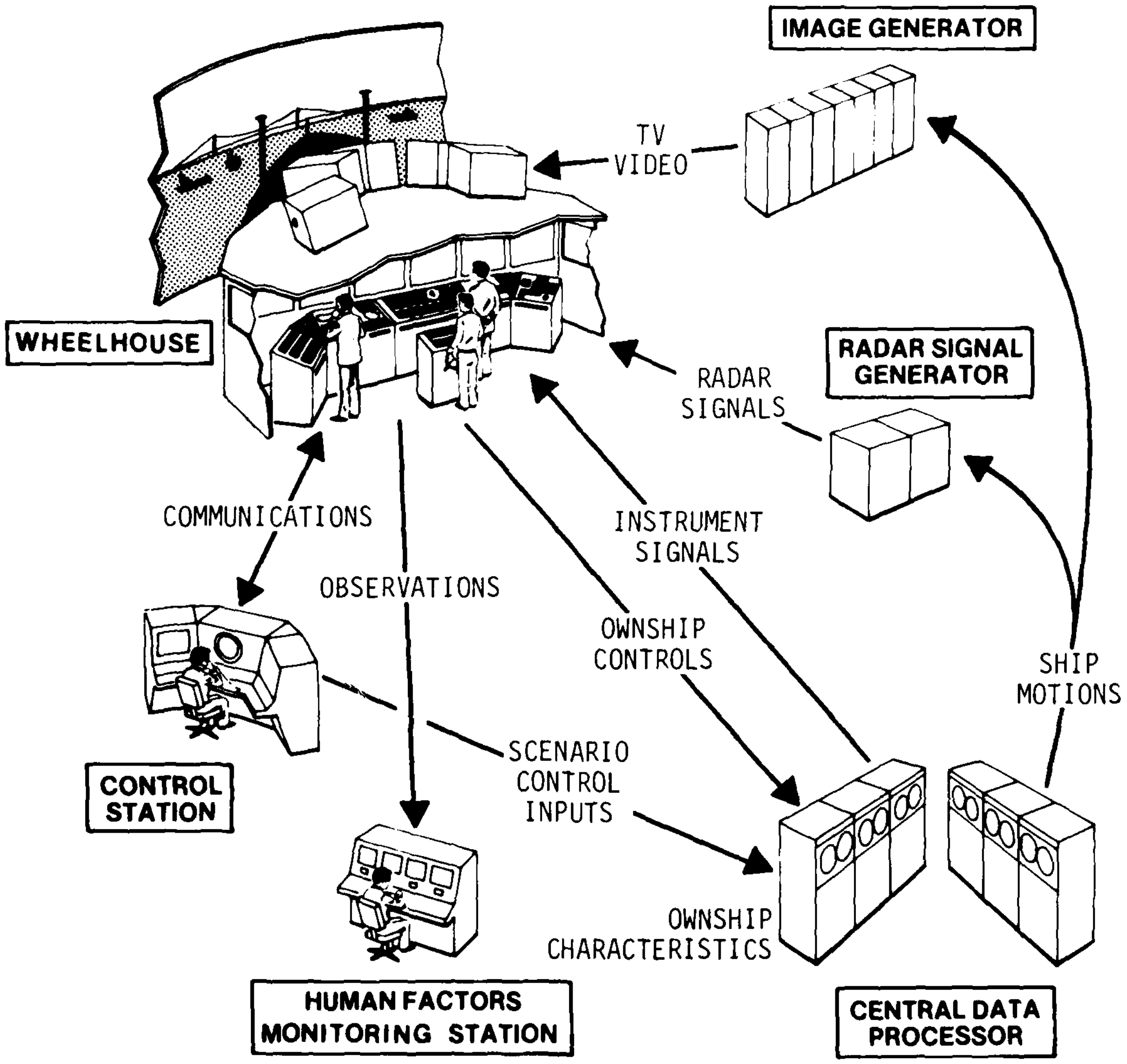

Figure A-2. Major CAORF Subsystems

A.3 OWNSHIP SIMULATION

Any ship can be simulated at CAORF. The computerized equations of motion are adapted to the ship by changing specific coefficients, among which are hydrodynamic, inertial, propulsion, thruster, rudder, aerodynamic, etc. Wind and currents realistically affect ship motion according to draft (loaded or ballasted) and relative speed and direction. Ownship's computer model was validated by comparing various simulated maneuvers (e.g., zig-zag, turning circle, spiral, crash stop, and acceleration tests) with sea trail data.

A.4 IMAGE GENERATION

The visual scene is generated at CAORF to a degree of realism sufficient for valid simulation. The scene (Figure A-3) includes all the man-made structures and natural components of the surrounding scene that mariners familiar with the geographical area deem necessary as cues for navigation.

Thus, bridges, buoys, lighthouses, tall buildings, mountains, glaciers, piers, coastlines, and islands would be depicted in the scene. In addition, the closest traffic ships and the forebody of

Figure A-3. Typical Simulated Visual Scene at CAORF

ownship appear. All elements in the scene appear to move in response to ownship's maneuvers. The sky is depicted without clouds and the water without waves.

For enhanced realism the scene is projected in full color. The perspective is set for the actual bridge height above waterline for the simulated ship. Shadowing can be varied according to the position of the sun at different times of day.

Environmental conditions also affect the scene. The lighting can be varied continuously from full sun to moonless night. At night, lights can be seen on traffic vessels, buoys, piers, and other points ashore. Visibility in the day or night can be reduced to simulate any degree of fog or haze.

A.5 RADAR SIGNAL GENERATION

The Radar Signal Generator produces real-time video signals for driving the two radar PPIs. The items displayed are synchronized with the visual scene and include navigation aids, ships, shorelines and other topographical features with appropriate target shadowing, clutter, range attenuation, and receiver noise. The radar gaming area, which covers an area of 150 by 200 miles, extends beyond the visual gaming area, which is 50 by 100 miles. Within the radar gaming area, as many as 40 moving traffic ships can be displayed. The radar signal generator also drives the collision avoidance system, which can be slaved to either of the master PPIs.

A.6 CONTROL STATION

The Control Station (Figure A-4) is the central location from which the simulator experiment is controlled and monitored. An experiment can be initiated anywhere within the visual gaming area with any ship traffic configuration. The Control Station enables the researchers to interface with the watchstanding crew on the bridge, to simulate malfunctions, and to control the operating mode of the simulator. The Control Station is also capable of controlling motions of traffic ships and tugs in the gaming area and simulating telephone, intercom, radio (VHF, SSB) and whistle contact with the CAORF bridge crew.

A.7 HUMAN FACTORS MONITORING STATION

The Human Factors Monitoring Station (Figure A-5) is designed to allow collection of data on crew behavior. Monitoring data is provided by five closed-circuit TV cameras and four microphones strategically located throughout the wheelhouse to record all activities, comments and commands.

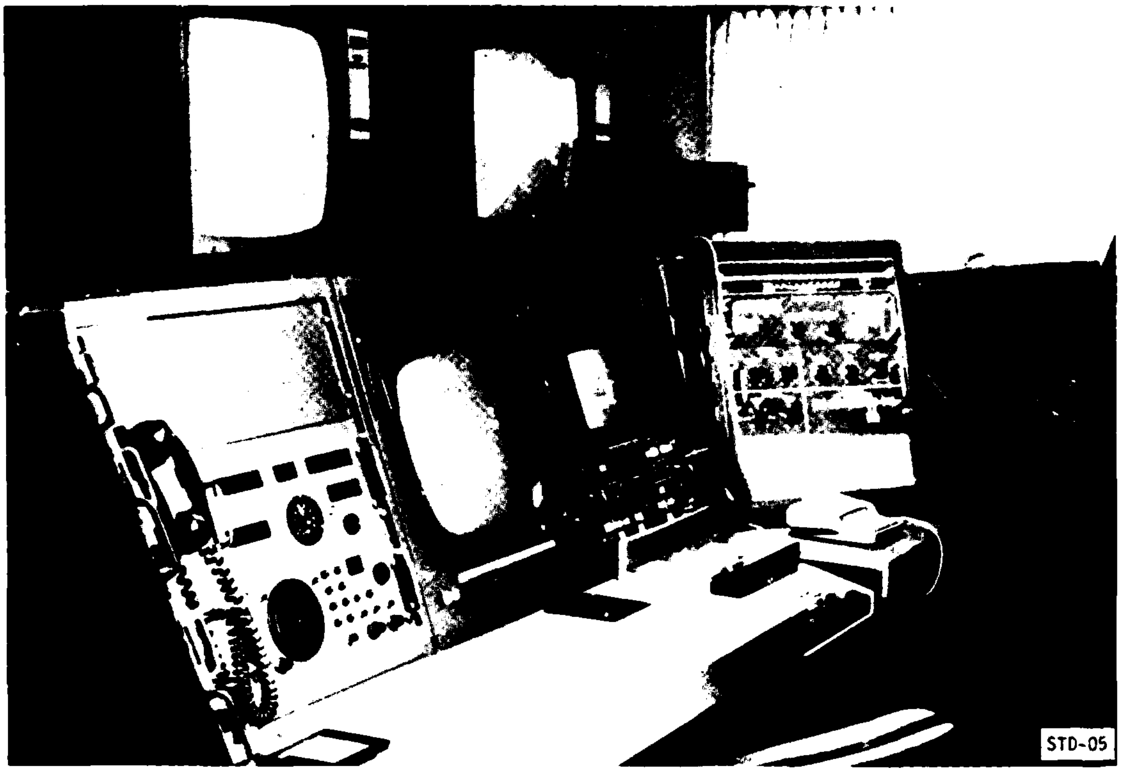

Figure A-4. Control Station

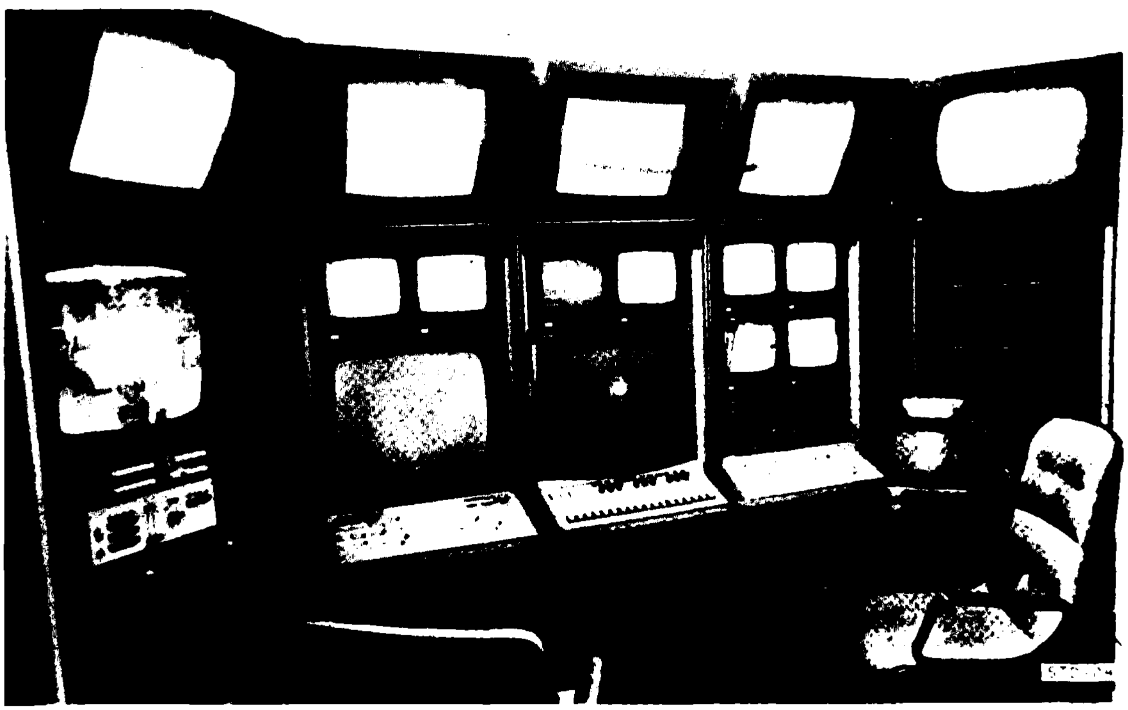

Figure A-5. Human Factors Monitoring Station

APPENDIX B

OFF TRACK DEVIATION

TABLE B-1. OFF TRACK DEVIATION MEANS FOR SIMULATOR EXPERIENCE, VALDEZ EXPERIENCE, AND TRIALS*

Group	Trials					
	All	1	2	3	4	5
All Subjects	-	-177.7	-107.3	-72.3	-40.2	-30.8
Simulator	-56.7	-165.5	-70.3	-44.7	-4.5	1.1
No Simulator	-114.6	-189.7	-144.3	-100.0	-75.9	-62.8
Valdez	-50.7	-176.5	-24.1	-40.6	-3.6	-8.8
No Valdez	-120.6	-178.7	-109.5	-104.1	-76.8	-52.0
Simulator/ Valdez	-50.7	-210.5	-29.8	-33.0	15.4	9.1
Simulator/ No Valdez	-62.7	-120.5	-110.7	-56.3	-24.4	-1.7
No Simulator/ Valdez	-50.7	-142.5	-18.4	-48.1	-22.7	-21.7
No Simulator/ No Valdez	-178.4	-236.9	-270.2	-151.9	-129.1	-103.9

* Negative Numbers = Feet left of track;
Positive = Feet right of track

APPENDIX C

PERCENT OF TIME OUT OF TOLERANCE

TABLE C-1. MEAN PERCENT OF TIME OUT OF TOLERANCE FOR SIMULATOR EXPERIENCE, VALDEZ EXPERIENCE AND TRIALS

Group	All	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
All Subjects	-	11.9	19.4	15.2	11.1	9.6
Simulator	11.9	19.4	16.0	12.0	6.9	5.2
No Simulator	19.7	27.4	23.2	18.5	15.4	14.1
Valdez	10.8	22.4	9.8	8.2	5.3	7.6
No Valdez	20.9	23.9	29.5	22.3	17.0	11.7
Simulator/ Valdez	11.8	23.8	13.5	7.4	6.6	7.0
Simulator/ No Valdez	12.0	14.9	18.6	16.6	7.2	1.5
No Simulator/ Valdez	9.7	21.9	6.1	9.0	4.0	7.3
No Simulator/ No Valdez	29.7	32.9	40.4	27.9	26.8	20.9

APPENDIX D

MULTIPLE RANGE STATISTICS

D.1 DUNCAN'S MULTIPLE RANGE STATISTIC FOR OFF TRACK DEVIATION

D.1.0 Overall Group Means †

	Simulator/ Valdez X_1	No Simulator/ Valdez X_3	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	-50.794	-50.733	-62.797	-178.469
X_1	-	.061	12.003	127.675*
X_2		-	12.064	127.736*
X_3			-	115.672*
X_4				-

*p< .05

† Differences between each pair of means are presented here. Significant differences are noted with asterisk.

D.1.1 Group Means at Trial 1

	Simulator/ No Valdez X_2	No Simulator/ Valdez X_3	Simulator/ Valdez X_1	No Simulator/ No Valdez X_4
Means	-120.571	-142.534	-210.542	-236.983
X_2	-	21.963	89.971	116.411
X_3		-	68.008	94.448
X_1			-	26.441
X_4				-

NS

D.1.2 Group Means at Trial 2

	No Simulator/ Valdez X_3	Simulator/ Valdez X_1	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	-18.445	-29.864	-110.768	-270.836*
X_3	-	11.419	92.323	251.836*
X_1		-	80.904	240.417*
X_1			-	159.513*
X_4				-

*p<.01

D.1.3 Group Means at Trial 3

	Simulator/ Valdez X_1	No Simulator/ Valdez X_3	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	-33.0381	-48.175	-56.380	-151.9866
X_1	-	15.1369	23.342	118.9485
X_3		-	8.205	103.8116
X_2			-	95.6066
X_4				-

NS

D.1.4 Group Means at Trial 4

	Simulator/ Valdez X_1	No Simulator/ Valdez X_3	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	15.440	-22.754	-24.490	-129.162
X_1	-	38.194	39.93	144.602*
X_3		-	1.736	106.408
X_2			-	104.672
X_4				-

*p< .01

D.1.5 Group Means at Trial 5

	Simulator/ Valdez X_1	Simulator/ No Valdez X_2	No Simulator/ Valdez X_3	No Simulator/ No Valdez X_4
Means	4.033	1.7768	-21.756	-103.937
X_1	-	5.81	25.789	107.97
X_2		-	19.979	102.16
X_3				82.181
X_4				-

NS

D.2 DUNCAN'S MULTIPLE RANGE STATISTIC FOR TIME OUT OF TOLERANCE

D.2.0 Overall Group Means

	No Simulator/ Valdez X_3	Simulator/ Valdez X_1	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	9.724	11.887	12.016	29.795
X_3	-	2.163	2.292	20.071*
X_1		-	.129	17.908*
X_2			-	17.779*
X_4				-

*p<.01

D.2.1 Group Means at Trial 1

	Simulator/ No Valdez X_2	No Simulator Valdez X_3	Simulator/ Valdez X_1	No Simulator No Valdez X_4
Means	14.958	21.982	23.854	32.925
X_2	-	7.024	8.896	17.967*
X_3		-	1.872	10.943
X_1			-	9.071
X_4				-

*p<.01

D.2.2 Group Means at Trial 2

	No Simulator/ Valdez X_3	Simulator/ Valdez X_1	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	6.120	13.560	18.625	40.422
X_3	-	7.44	12.505*	34.302**
X_1		-	5.065	26.862**
X_2			-	21.797**
X_4				-

*p< .05 **p< .01

D.2.3 Group Means at Trial 3

	Simulator/ Valdez X_1	No Simulator/ Valdez X_3	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	7.478	9.09	16.664	27.939
X_1	-	1.612	9.186	20.461*
X_3		-	7.574	18.849*
X_2			-	11.275
X_4				-

*p< .01

D.2.4 Group Means at Trial 4

	No Simulator/ Valdez X_3	Simulator/ Valdez X_1	Simulator/ No Valdez X_2	No Simulator/ No Valdez X_4
Means	4.05	6.622	7.238	26.853
X_3	-	2.572	3.188	22.803*
X_1		-	.616	20.231*
X_2			-	19.615*
X_4				-

p< .01

D.2.5 Group Means at Trial 5

	Simulator/ No Valdez X_2	No Simulator/ Valdez X_3	Simulator/ Valdez X_1	No Simulator/ No Valdez X_4
Means	2.596	7.38	7.924	20.8360
X_2	-	4.784	5.328	18.24*
X_3		-	.544	13.456*
X_1			-	12.912*
X_4				-

*p< .05

END

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